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EVALUATION OF FUNCTIONAL CAPACITY AND EXERCISE TOLERANCE OF CARDIAC PATIENTS

I. Functional Capacity

Definition

Functional capacity of a cardiac patient is merely "an estimate of what the patient's heart will allow him to do"[1]. It is determined subjectively by the physician, independently of diagnostic findings, treatment or prognosis. It is not to be confused, therefore, with therapeutic classification which represents a physician's opinion or advice about what the patient may safely and properly do. Functional capacity is a relationship of symptoms of cardiac impairment to the stresses of physical activity considered ordinary by the patient. Cardiac impairment is recognized clinically by dyspnea, orthopnea, fatigue, palpitation, anginal pain or other less specific symptoms. The threshold, intensity and duration of these symptoms vary from patient to patient, and even within the same patient from time to time. The spectrum of physical activities is very broad; what is considered ordinary by one patient may be extraordinary for another.

Because there are so many variables, determination of functional capacity requires the patience and skill of the physician to elicit the history of symptoms, limitations and course of illness. He is dependent upon the patient or his family being able to give a clear and accurate medical history. Some patients are excellent historians, others are not. The physician must not only differentiate symptoms of impaired cardiac function from those of other disease processes or psychoneurotic disorders, but must also establish the diagnosis of heart disease.

Classification

Classification of functional capacity is determined by the relative severity of symptoms and limitation of ordinary physical activities according to the criteria of the New York Heart Association (Table I.) It may be helpful to supplement these criteria with two others. One is the approximate duration of time that these activities can be continued without discomfort. The other is the need for rest as determined spontaneously by the patient. Initially, he may require additional rest in the evenings and over weekends, tending to sacrifice recreational activities. Later he may be forced to rest part of each working day. The work record is another important guide, whether it be for a child in school, a housewife or an employee in industry. But due care must be taken to recognize an anxious patient who limits himself excessively, as well as the highly motivated patient who, despite symptoms, continues effort beyond his capacity.

Ability to perform greater than ordinary daily activity without discomfort constitutes the norm for functional capacity. Class I patients closely approach this, for despite evidence of heart disease, they exhibit no symptoms or limitations. Class II patients experience symptoms or limitations to a minor degree with ordinary activity. They have little need for additional rest, and usually continue their activities on a full time schedule. Functional capacity is significantly impaired for Class III patients who experience symptoms with less than ordinary activity. These patients have a marked limitation of activity and a definite need for rest. Often they are unable to continue on a full time schedule. Class IV patients have extreme limitations of activity, frequently are uncomfortable at rest, and are unable to work at all. They are virtually unable to do anything without discomfort. Usually there is little difficulty in recognizing Class I or Class IV patients. Whenever patients or their families are poor historians, it may not be possible to clearly define symptoms, limitations of activity, need for rest or give an adequate work record. Then classification of functional capacity in the intermediate ranges may be uncertain. Furthermore, unless the patient exhibits signs of congestive heart failure, little assistance may be obtained from physical examination at rest.

Importance

Accurate classification of functional capacity is important whenever major decisions must be made concerning the management of a patient.

From the School of Medicine, University of Washington, Seattle, Washington.

TABLE I

CLINICAL EVALUATION OF FUNCTIONAL CAPACITY OF PATIENTS WITH HEART DISEASE IN RELATION TO ORDINARY PHYSICAL ACTIVITY

(Modified from New York Heart Association, 1953)

Class	Cardiac Symptoms	Limitations	Need for Additional Rest‡	Physical Ability to Work*
I	None	None	None	Full Time
II	Only Moderate	Slight	Usually Only Slight or Occasional	Usually Full time
III	Definite, with less than ordinary activity	Marked	Usually Moderate	Usually Part Time
IV	May be present even at rest, and any activity increases discomfort	Extreme	Marked	Unable to work

‡To control or relieve symptoms, as determined by the patient, rather than advised by the physician.
*At accustomed occupation or usual tasks.

For example, following convalescence from a myocardial infarct, a decision must be made whether the patient, who is often the head of a family, can return to his former job, with or without restrictions. If the patient remains free of symptoms with graded increases in physical activity, a point may be reached when it seems reasonable and proper for him to resume work, at least on a part-time basis initially. Often there is considerable apprehension on the part of the patient, his family, physician and employer about the wisdom of such advice. The multi-discipline approach of Work Classification Clinics has been most helpful to many patients in this regard. The patient's reaction to his illness and socio-economic factors play important roles in many instances, but the basic problem is whether the patient has sufficient functional capacity to resume former responsibilities. Since some patients are more disabled by psychogenic factors than by organic illness, classification of functional capacity may be difficult, if not impossible, without some objective evaluation of exercise tolerance.

II. Exercise Tolerance

Definition

Exercise tolerance is self-explanatory, yet it has little meaning unless the form and conditions of exercise are defined. With respect to the evalnuation of cardiac function, exercise tolerance still has little significance unless the demands for circulation are sufficient to represent a valid stress on the heart, and appropriate measurements are made of the response to this stress. The clinical and physiological response to exercise of the cardiac patient varies with motivation, the physical and emotional status, functional capacity, and the natural history of the disease and its complications. Consequently, there are many variables that have to be controlled, if possible.

Previous tests of exercise tolerance have been either poorly standardized or too limited in scope to provide as much scientific objectivity as is possible. Precise methods with a suitably standardized procedure have much to offer in this regard. A common form of exercise is necessary in order to test a wide spectrum of patients of varying age and degree of skill and disability. The work load should be sufficient to increase the oxygen requirement at least 3 times in order to reliably differentiate between varying degrees of cardiac impairment. Since many patients require more than 3 minutes to achieve a steady state, sufficient time is important. Adequate time to observe recovery from such a stress is also required. The procedure should be simple, safe and require no special skills for its performance. It should, of course, be properly supervised and should not be delegated to a technician, for prompt termination of the test is mandatory whenever an occasional patient develops signs of cardiac impairment without warning symptoms. Finally, such tests should never precede clinical examination of the patient, for there are definite contraindications such as recent myocardial infarction, acute myocarditis, marked heart failure, recent pulmonary embolism, or ventricular tachycardia.

In essence, a test of exercise tolerance may represent physical examination of the patient in relation to a reproducible amount of work. With precautions as noted above, it is a safe procedure.

Laboratory Methods and Principles of Evaluation

An improved method of testing exercise tolerance has been developed to meet these requirements in the laboratory. A motor driven treadmill is employed to regulate the rate of energy expenditure. Ambulatory patients are easily instructed how to walk slowly at the rate of 150

feet per minute (1.7 mph) on a 10 per cent grade. After sitting for 4 minutes and standing for 1 minute, patients exercise for 10 minutes, unless limited by poor tolerance. Observations are continued through a 5 minute period of recovery, with the patient in a sitting position. This work load is less severe, but more prolonged than Master's two-step test. Experience has demonstrated the value of direct observation of cardiac patients in response to this standard procedure.

The left precordial lead electrocardiogram is recorded each minute, even during exertion. A chest belt holds three electrodes. The right arm cable is attached to a posterior electrode which is positioned near the tip of the right scapula. The left arm cable is attached to an anterior electrode near the apical impulse. The latter is positioned in V_4 or V_5 location, whichever exhibits the highest R wave in the conventional 12 lead electrocardiogram taken during rest. The right leg cable is attached to a third electrode on the right side of the chest for the purpose of grounding the patient. The tracing, which is recorded from lead I position of the selector switch of the electrocardiograph, is designated "CB_4" or "CB_5" to indicate the use of these particular reference points, where "C" refers to the precordial area of the chest and "B" refers to the back of the chest. This terminology differentiates this tracing from the conventional V_4 or V_5 tracing based upon utilization of Wilson's central terminal derived from three of the limb leads. Thus, there are no cables attached to the limbs to encumber the patient while walking. Electrocardiographic changes during exercise and recovery are interpreted in relation to findings recorded during the 4th minute of rest, while the patient is sitting, and prior to standing and walking.

Changes in blood pressure are detected with a clinical sphygmomanometer attached to the arm. The patient wears a face mask to permit collection of expired air for continuous analysis of oxygen concentration. The difference between oxygen concentration in inspired air (20.9 volumes per cent) and the average concentration in expired air during exercise is a highly reproducible measurement of pulmonary function that is designated "respiratory efficiency."

Exercise tolerance is evaluated in respect to symptoms, signs and physiological responses as follows:

1. The duration of time, when less than 10 minutes, is the simplest measure of exercise tolerance. The spontaneous decrease of endurance on the part of the patient, in the absence of signs and symptoms, is indicative of inappropriate motivation or undue apprehension. This may be corrected when it is encountered by orienting the patient as to the purpose and importance of the test, and reassuring him that he is being carefully supervised.

2. The patient is questioned about the intensity of dyspnea, fatigue, palpitation, chest pain, dizziness, aching of the legs or other symptoms. Each is graded as absent, slight, moderate or marked. Since intensity of symptoms may be increased by apprehension or anxiety, this should be noted too.

3. The patient is examined immediately after exertion for evidence of diastolic gallop rhythm, appearance of murmurs, pulmonary congestion, or venous hypertension.

4. Abnormal responses are defined as:
   a. Tachycardia over 135 per minute during effort.
   b. Failure during exercise to increase and maintain systolic blood pressure 10 mm. or more above resting level.
   c. "Rebound" of systolic pressure during recovery over 4 mm. above highest exercise level.
   d. Ventricular premature beats, or paroxysmal ventricular tachycardia during exercise.
   e. ST depression greater than 2 mm., change in direction of T, or marked increase in QT/TQ ratio over 2.5 during exercise or recovery, when compared with control tracing taken during 4th minute of sitting before exercise.
   f. Average respiratory efficiency less than 4.2 volumes per cent during exercise.

5. Physical Fitness Index of exercise tolerance[2]:

$$PFI = \frac{(E)\ (r)\ (k)}{c}$$

where E = duration of exercise or endurance, in minutes
r = average respiratory efficiency during exertion
k = 100, and
c = cumulative heart rate for first 3 minutes of recovery.
Normal values for this test range from 13 to 26.

Significance of Abnormal Exercise Tolerance

Class I cardiac patients usually exhibit slight, if any, symptoms during the standard treadmill exercise tolerance test (Table II). Some patients with coronary artery disease may manifest mild electrocardiographic changes. Class II patients usually can walk for 10 minutes despite symptoms of moderate intensity, i.e. chiefly dyspnea and fatigue during exertion. Electrocardiographic abnormalities are more frequently encountered in Class II and Class III patients. Seriously disabled patients with functional capacity in Class III or IV generally are unable to continue effort for 10 minutes due to marked severity of symptoms. Because the rate of energy expenditure is regulated, the duration of time that exercise can be sustained is the simplest and most important measure of exercise tolerance. The changes in heart rate, blood pressure and precordial electrocardiogram follow in relative importance. Occasionally patients show a depression of sensorium, or begin to stagger during effort. These are presumptive manifestations of cerebral hypoxia, and definite indications for terminating the test. Either hypotension or paroxysmal ventricular tachycardia during exertion is a major sign of impaired cardiac function. When basilar rales of pulmonary congestion, or jugular

TABLE II

EXERCISE TOLERANCE OF CARDIAC PATIENTS*

Functional Capacity		I		II		III		IV
Etiological Group	N	C	R	C	R	C	R	R
Incidence of (Per cent)								
Dyspnea	0	36	17	22	53	93	86	83
Fatigue	0	18	25	48	43	73	86	72
Chest Pain	0	9	8	*42*	8	*73*	17	18
Abnormal								
ECG Responses	0	27	25	48	45	60	68	47
Blood Pressure Responses	0	0	*25*	8	*41*	23	*57*	*69*
Average Exercise								
Endurance, minutes	10	10	9.6	9.7	8.8	5.2	6.0	1.6
Heart Rate	123	121	136	126	141	129	153	138
Respiratory Efficiency, Vol. %	5.0	4.9	4.7	4.4	4.2	4.5	*3.6*	*3.0*
Physical Fitness Index	17	17	16	15	13	9	9	2

* 247 patients tested on a treadmill at 1.7 mph and 10 per cent grade.
N = Normal Subjects
C = Coronary Artery Disease with previous myocardial infarction.
R = Rheumatic Heart Disease with one or more valvular lesions.
Important differences between etiological groups are in italics.

venous pulsation due to tricuspid incompetence occur as a result of exercise, there is definite evidence of cardiac insufficiency. Obviously, personal supervision of the test by a physician is not only important for the safety of the patient, but provides an unexcelled opportunity to observe the mechanisms of cardiac dysfunction which may be responsible for symptoms. This procedure of physiologic evaluation of exercise in the *upright* posture aids the clinical evaluation of the patient. It will be improved further when it is possible to readily determine cardiac output and coronary blood flow relative to oxygen requirements and vascular resistance.

The physical fitness index may be increased by factors which slow the heart rate, such as physical training, ventricular hypertrophy or overtreatment with digitalis. Contrariwise, it may be decreased by tachycardia or hyperventilation associated with anxiety. Usually each of these factors may be detected by clinical evaluation.

Abnormal patterns of exercise response emerge in relation to types of heart disease (Table II). For example, chest pain is common in patients with previous myocardial infarction, but is infrequently noted in patients with valvular heart disease. Yet the latter just as commonly show electrocardiographic abnormalities. Patients with valvular lesions frequently exhibit tachycardia (especially with auricular fibrillation). They often have moderate "hypotension" and subnormal respiratory efficiency during exercise, with a "rebound" in systolic pressure during recovery. No single abnormality, however, is manifested exclusively by patients with any particular etiology or manifestation of heart disease.

Discrepancies occur between the subjective evaluation of functional capacity and the objective determination of exercise tolerance. Due to subjective limitations of the clinical methods employed, functional capacity of some patients is unintentionally either overestimated or underestimated. These considerations become important whenever the effects of the treatment of heart disease on functional capacity are critically evaluated[3].

In our experience, exercise testing has been of distinct value in the clinical selection of patients for mitral commissurotomy[4]. Maximal benefit is likely to occur in patients with subnormal PFI values ranging from 3 to 6 despite intensive and prolonged medical treatment. Patients with lower values incur the risk of an operative death. Similarly, evaluation by the above technic has facilitated the management of the cardiac patient during pregnancy.[5]

Recommendations regarding cardiac rehabilitation are greatly strengthened by knowledge of the patient's performance[6]. The work load required for the treadmill test represents a higher rate of energy expenditure than observed for all but the more vigorous physical work requirements in industry. Consequently, the ability to perform this test without having the patient develop symptoms or abnormalities affords some indication of the physical capacity for work. The work record is the best evaluation of the stamina of the cardiac employee.

Wuest and his associates have studied the exercise tolerance and work performance of cardiac patients in industry[7] in an attempt to correlate physiological requirements and capacity for work. They found that patients in Classes I and II usually were able to work full time, whereas the occasional cardiac employee in Class III who was still trying to work full time was likely to be working beyond his physical capacity. With respect to this test of exercise tolerance, their findings were similar to ours for both healthy employees and those with cardiac dis-

ease. In addition, whereas normal subjects of corresponding age required an average of 2.6 minutes to attain a steady state of oxygen consumption, patients in Class I required an average of 2.9 minutes and patients in Class III required an average of 3.3 minutes. Oxygen debt increased from 12 per cent in normals to 14, 32 and 55 per cent for cardiac patients in Classes I, II and III, respectively.

Exercise tests do not establish etiological or anatomical diagnoses, but they may provide data that can be evaluated clinically as ancillary laboratory evidence. Abnormal exercise tolerance in a patient does not specifically indicate cardiac disease. The relationship of symptoms, disease and functional impairment is established clinically by examination of all the pertinent findings. Nevertheless, exercise tests, when they are properly supervised, standardized and evaluated, supplement the usual clinical observations by providing precise measurements of exercise tolerance. Since they may correct errors in clinical evaluation of functional capacity, they have real value in the management of cardiac patients who have clinically difficult problems.

Clinical Office Tests

Technics involving research laboratory methods are not applicable to clinical office practice. However, some of the principles can be applied with appropriate modifications. The essential requirements are simplicity of procedure, standardization of method*, use of readily available instruments, and observation of basic characteristics of exercise performance. This may be accomplished with a single step 8 to 9 inches high[8]. The patient is instructed to step up on the step, and back down on the floor, at the rate of 20 times per minute, or one complete cycle every 3 seconds. A metronome helps the patient regulate the speed of stepping. This effort is comparable to that of walking on the treadmill ergometer on a 10 per cent grade at 1.7 mph, for it increases oxygen consumption 3 to 4 times above the resting level. This exercise is continued for 10 minutes, or to limits of tolerance if the patient is unable to continue it for 10 minutes. The duration of effort—endurance—is carefully timed. Precordial lead electrocardiograms are recorded in the same manner as described for the treadmill procedure above. This is done regularly each minute while the patient sits for 4 minutes, stands for 1 minute, steps up and down for 10 minutes and then again sits for 5 minutes. Instead of elaborate equipment to determine oxygen tension of expired air, a small piece of paper, bent into "L" shape, is attached to the nose with scotch tape. Since the paper moves with each breath it facilitates counting respirations during exercise. The ratio

$$\frac{100}{\text{average respiratory rate}}$$

roughly correlates with average respiratory efficiency during exercise. Consequently, the formula for physical fitness index is modified as follows for this *step test*[8]:

$$\text{PFI} = \frac{\text{E}\,(\text{k}')}{(\text{r}')\,(\text{c})} \times \frac{\text{s}}{20}$$

Where E = endurance, in minutes
$k' = 100 \times 100$ or 10,000
r' = average respiratory rate during exercise
c = cumulative heart rate for first 3 minutes of recovery
s = average number of steps per minute. (This corrects for variations in amount of work performed when patients are unable to do exactly 20 steps per minute)

The normal values for this particular test range from 9 to 19 with an average of 14. In general, there is a satisfactory correlation between PFI values for this step test and PFI values for the treadmill test, as calculated by the original formula. The respiratory rate is more variable and hence somewhat less satisfactory than respiratory efficiency as a measure of pulmonary function during effort. The maximal normal rate is 32 respirations per minute.

In addition, it is important to evaluate symptoms and to look for evidence of venous hypertension, pulmonary congestion, cyanosis, or gallop rhythm. Changes in the precordial lead electrocardiogram and abnormalities of blood pressure responses are evaluated in the same manner as for the treadmill exercise test. This procedure has been safe and valuable in office practice[9].

Many physicians, undoubtedly, will find even this step test too elaborate and too time consuming for every day use. Again, the principles may be applied to a very simple procedure with some benefit. The step on the end of an examining table may be used, and the patient requested to step up and down at a rate of 20 steps per minute for 10 minutes, or to the limits of tolerance. The *duration of time* that this effort can be tolerated shows a satisfactory correlation with physical fitness index whenever endurance is less than 10 minutes. The busy practitioner should not delegate this procedure to his nurse or technician because occasionally patients exhibit important symptoms or signs that require immediate cessation of effort*.

A variety of other tests have been used by various physicians and investigators. Although Warring's Walking Ventilation Index[10] was proposed for evaluation of pulmonary function and especially for ventilatory function in patients with tuberculosis, it is equally suited for evaluation of dyspnea and ventilatory function in cardiac patients when pulmonary disease is excluded by clinical examination. Dyspnea is rather severe when the ratio of minute ventilation to maximum breathing capacity exceeds 0.5 as a result of walking on a level for a distance of 180 feet

* A portable aluminum treadmill, requiring a floor space of 6 x 3 feet, has been designed for laboratory or clinic use. Information may be obtained from W. E. Quinton Instrument Co., 1832 Shelby Street, Seattle, Washington.

* (However, he may use this time to record his notes and still remain close to the patient during the procedure.)

in one minute. The Cournand and Richards step test, involving 30 steps for only one minute, is a well standardized procedure for evaluating pulmonary function from ventilatory and respiratory measurements[11]. Since cardiac patients do not achieve a steady state in one minute, and endurance is the simplest and most important single measurement of exercise tolerance, a less vigorous but more prolonged exercise procedure seems more desirable. Master's two-step test is also vigorous and too short in duration to be readily applicable for this purpose. Nevertheless, abnormal cardiac function is suspected whenever the heart rate and systolic pressure fail to return to within 10 points of resting values 2 minutes after exercise[12].

Many physicians have utilized stair climbing as a simple test. Patients able to climb a flight of stairs at an ordinary pace have little, if any disability. Those who are physically unable to climb stairs are severely disabled, whereas patients who develop symptoms, especially with slow rates of climbing, are moderately disabled. It is important for the physician to personally observe any of these procedures in order to obtain the greatest possible information. Sometimes a patient's description of his symptoms in respect to stair climbing is misleading until one learns how slowly or rapidly he climbs and whether or not he rests along the way.

Electrocardiographic Changes

In the absence of other evidence, clinical diagnoses of coronary insufficiency have often been made on the basis of electrocardiographic changes *following* exercise, for example Master's two-step test[12]. Tracings taken *during* a step test may show changes that are not always present immediately after exercise[13]. Consequently, this modification increases the sensitivity and value of such tests. Furthermore, paroxysms of ventricular tachycardia during exercise warn the physician that effort should be discontinued, even in the absence of symptoms. Although this arrhythmia is an infrequent occurrence, nevertheless this type of monitoring is an important safety precaution whenever exercise tests are used to evaluate function in cardiac patients. Occasional ventricular premature beats, marked ST depressions or marked changes in T waves have not been considered indications for stopping the test. Undoubtedly many of these patients develop similar changes, which are not recorded, whenever they exert themselves enough to increase oxygen consumption 2 or 3 times in every day living. Except for the rare patient who develops cerebral hypoxia, these patients will usually limit their activity when they experience symptoms.

The interested reader will find critical studies of the associated effects of heavy meals[14] and variations in exercise stress in relation to electrocardiographic changes reported elsewhere[15,16]. The importance of standardizing both stress and the criteria for abnormalities has been demonstrated by the observation of similar changes in normal subjects under unusual stresses[17,18]. The exercise tests described above are standard procedures, within reasonable limits, and are useful for the detection of coronary insufficiency as well as for evaluation of exercise tolerance.

Conclusions

1. The clinical estimate of functional capacity of cardiac patients is limited by the necessity of subjective evaluation of numerous variables.
2. An exercise test, when properly utilized, permits an unexcelled opportunity to observe the response of patients to effort and to objectively determine functional capacity.
3. Exercise testing is practical and valuable whenever important decisions must be made regarding the management of the cardiac patient.

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ABSTRACTS OF PAPERS

for

THE 29th ANNUAL SCIENTIFIC SESSIONS,

AMERICAN HEART ASSOCIATION

The 29th Annual Scientific Sessions of the American Heart Association will be held in Cincinnati, Ohio, October 27, 28, 29, 1956 in conjunction with the Association's Annual Meeting. The deadline for submission of abstracts has been extended to June 15. Abstracts will be accepted only on forms which may be obtained from the Medical Director, American Heart Association, 44 East 23rd Street, New York 10, New York.

Papers intended for presentation should be based on original investigations in or related to the cardiovascular field. The abstracts must be 300 words or less and should contain in summary form the results obtained and the conclusions reached. Abstracts must be submitted in triplicate.

The Scientific Sessions this year will feature an enlarged section for Scientific Exhibits. Requests for space and application forms can also be obtained from the Association's Medical Director. The deadline for these applications has been extended to June 15, 1956. All exhibit applications will be acted upon by the Program Committee of the Scientific Council.

INTERNATIONAL CARDIOLOGY MEETINGS

Second European Congress of Cardiology

The Second European Congress of Cardiology will be held in Stockholm, Sweden, September 10-14, 1956, under the presidency of Professor Gustav Nylin. The Secretary-General for the Congress is Dr. Karl Erik Grewin, Sodersjukhuset, Stockholm, Sweden.

Fifth Interamerican Congress of Cardiology

The Fifth Interamerican Congress of Cardiology will be held in Havana, Cuba, November 11-17, 1956. Dr. Ramon Aixala of Havana is President of the Cuban Committee for the Congress, which is sponsored by the Interamerican and Cuban Societies of Cardiology. The Secretary-General is Dr. Rafael Perez Diaz, Al Apartado 2108, Havana, Cuba. Those interested in attending this meeting should note that it has been postponed one week from the dates originally announced.

Third World Congress of Cardiology

The Third World Congress of Cardiology will be held in Brussels, Belgium, in September 1958, under the chairmanship of Professor P. Rijlant. The Secretary-General for the Congress is Dr. Fr. Van Dooran, 80 Rue Merceles, Brussels, Belgium.